EVALUATION OF THE RELATIVE SUITABILITY OF POTENTIAL JAGUAR HABITAT IN NEW MEXICO

KURT A. MENKE, Earth Data Analysis Center, MSC01 1110
1 University of New Mexico, Albuquerque, NM 87131-0001
CHARLES L. HAYES, New Mexico Department of Game and Fish, One Wildlife Way, Santa Fe, NM 87507.

Abstract: We conducted a spatial analysis of potential habitat for the jaguar (*Panthera onca*) in New Mexico. We used a geographic information system (GIS) model to combine data layers for landscape features influencing suitability for jaguar habitat, and created a composite potential habitat map. The model predicted two areas with the highest probability of being able to support jaguars in New Mexico. These areas were the Peloncillo and Animas Mountains in far southwestern New Mexico, and the river canyon and adjacent areas of the Gila and San Francisco River drainages along the New Mexico-Arizona border and to the east. We did not define these two areas as “suitable” for breeding populations of jaguars, nor were slightly less suitable habitats classified as “unsuitable”. The results of this study should be combined with similar efforts from Arizona and Mexico to help further evaluate the connectivity of suitable habitats, and their ability support a jaguar metapopulation at the northern end of the species range.

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INTRODUCTION

The jaguar reaches the northern extent of its geographic range in the southwestern United States (Bailey 1932, Goldman 1932, Halloran 1946, Findley 1975, Seymour 1989, Rabinowitz 1999). Fossil and historic records place the jaguar among fauna that was regularly present in the southern United States (Nelson and Goldman 1933, Findley 1975, Seymour 1989, Brown and Lopez Gonzalez 2000). The scarcity of jaguar specimens from the United States since about 1910 has led to significant debate as to whether more recent observations indicate presence of a breeding population, or transient individuals from Mexico (Findley 1975, Hoffmeister 1986, Rabinowitz 1999, Brown and Lopez Gonzalez 2001). Based on the distributional decline of the jaguar and threats of take by illegal harvest and other means, the jaguar north of the U.S.- Mexico border was listed as ″endangered″ under the Endangered Species Act (ESA) in 1997 (Federal Register 1997). This action reversed the removal of ESA protection for jaguars in the United States that resulted from a procedural oversight when the ESA superceded the Endangered Species Conservation Act in 1973.

During the period when the jaguar was proposed for listing under the ESA, a multi-party, multi-agency group wrote and signed a Memorandum of Understanding implementing the

<u>Conservation Assessment and Strategy for the Jaguar in Arizona and New Mexico</u> (Johnson and Van Pelt 1997). Together, these documents comprised a conservation agreement (CA) and called for the establishment of a jaguar conservation team (JAGCT), jaguar scientific advisory group (JAGSAG), and jaguar habitat subcommittee (JAGHAB). One of the tasks described within the CA was to identify suitable habitat for jaguars in New Mexico and Arizona. Results of this analysis are beneficial in helping to focus conservation efforts on those areas with the greatest probability of jaguar occurrence within the United States, and to thereby direct any management actions in to those areas where the greatest conservation benefits would be expected.

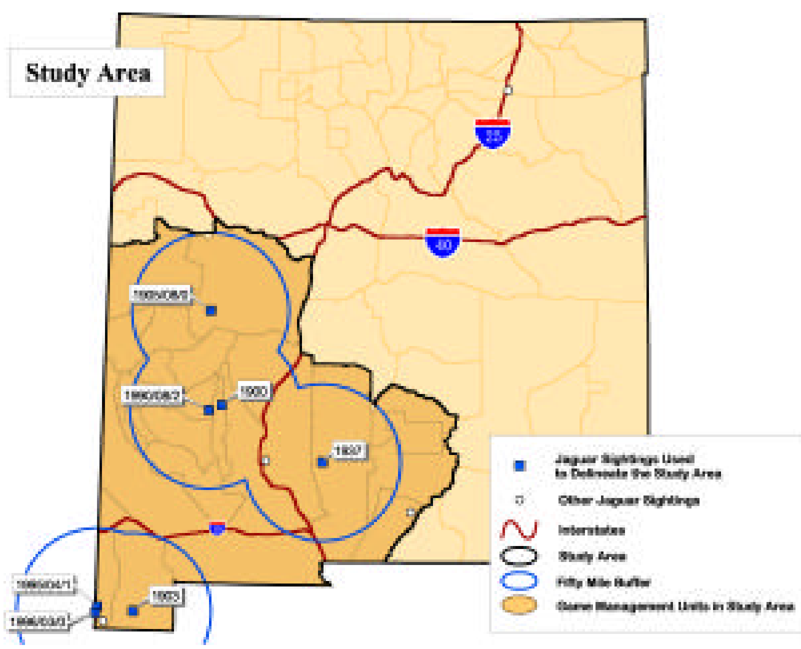

Figure 1. Study Area Delineation

STUDY AREA

We defined the geographic extent of the study area (Figure 1) as areas within 50 miles of jaguar observations accompanied by physical evidence (Class 1) or reported as first-hand observations from a reliable source (Class 2). We included only those sightings that were reported with sufficient locational precision to reliably plot and analyze their locations (Table 1). For example, the study area definition did not consider sightings that were reported only with general locations e.g., ″Otero County″. We extended the study area boundary to include entire New Mexico Big Game Management Units (19.30.4.8 New Mexico Administrative Code renumbered 2001) that intersected the 50-mile buffer, to be inclusive of (as opposed to bisecting) contiguous mountain ranges and potential prey populations (Figure 2).

Table 1. Jaguar reports and records from New Mexico used to define the boundaries of the study area.

Year	County/Mountain Range	Observed By	Reported In
1900	Sierra/Black Range	N. Straw	Barber (1902)
1903	Hidalgo/Peloncillo Mtns.	W. P. Burchfield	Bailey (1932)
1905	Catron/Datil Mtns.	N. Hollister	Bailey (1932)
1937	Sierra/San Andres Mtns.	Bannerman	Halloran (1946)
1990	Sierra/Black Range	G. Z. Jacobi	Jacobi memo (1990)
1995	Hidalgo/Peloncillo Mtns.	B. L. Starret	Holycross memo (1997)
1996	Hidalgo/Peloncillo Mtns.	W. Glenn	Glenn (1996)

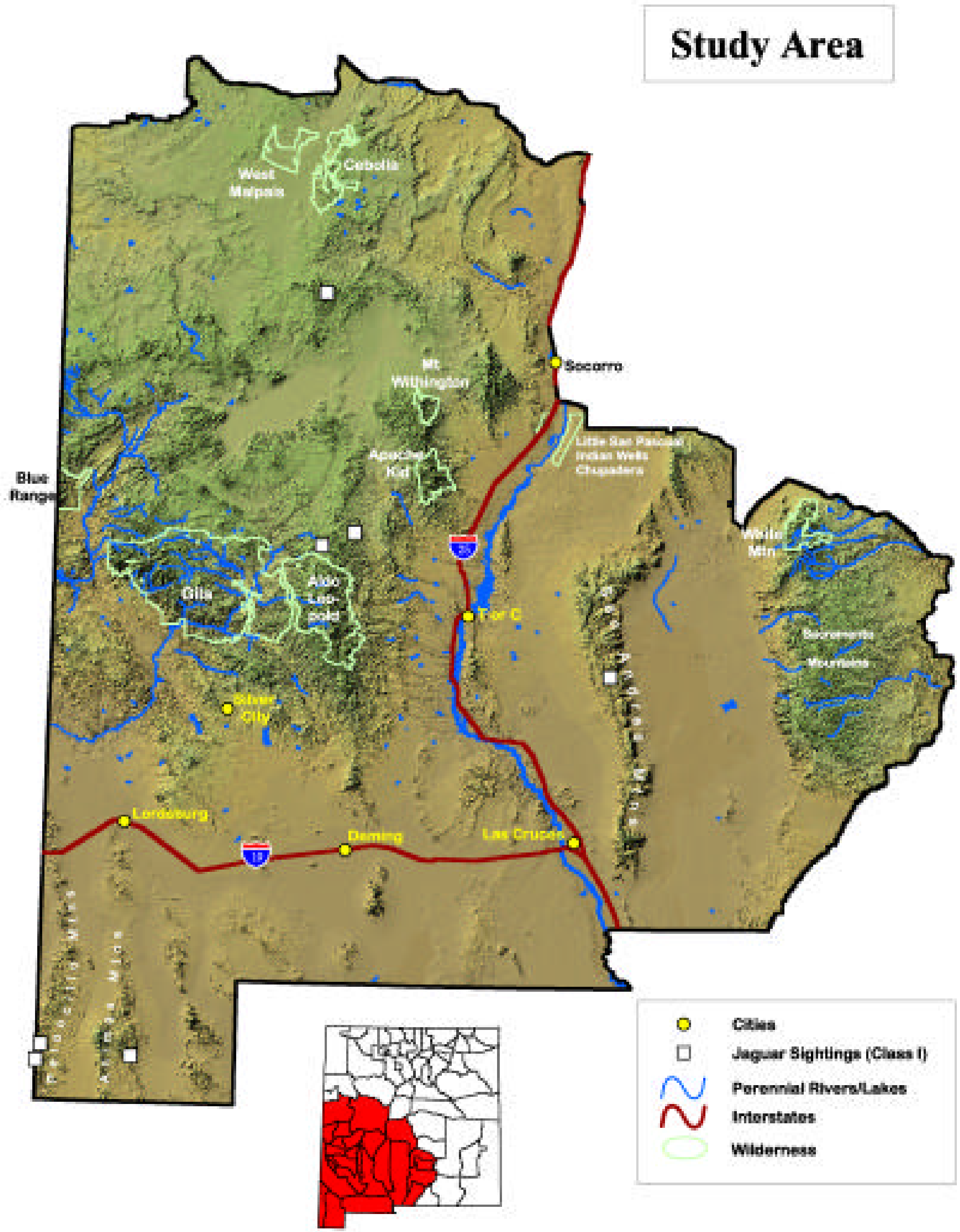

Figure 2. Study Area

METHODS

Selection of Variables

Due to the small number of documented jaguar locations, we did not attempt to determine patterns of habitat use for jaguars in New Mexico. We identified positive and negative potential habitat features for jaguars based on literature sources and evaluations from the JAGHAB and JAGSAG. We plotted reported jaguar observations for comparison purposes, but did not conduct any spatial analyses of these points, other than to delineate the study area. We incorporated potential habitat variables in New Mexico that were identified by the JAGSAG (Miller et al. 2000) and in the analysis of potential jaguar habitat in Arizona (Hatten et al. 2002). These variables were human density, vegetation community, distance to water, prey abundance, and terrain ruggedness. We obtained spatial New Mexico data layers for these variables and overlaid them using a GIS (ArcView Spatial Analyst/Model Builder 2.0a, ESRI, Redlands, CA). We used an arithmetic overlay to create a composite map identifying relative habitat suitability for jaguars, and weighted positive habitat indicators equally among the variables. We then classified the grid cells on the composite map into categories of relative suitability ranging from lowest habitat potential to highest habitat potential based upon visually-identified discontinuities (breaks) in the distribution of the data. However, because the number of verified, historical locations was too small to determine habitat requirements, we did not attempt to establish a threshold for suitable vs. unsuitable potential habitat, nor to determine whether or not any specific area could sustain a resident population of jaguars.

Human Density

The Arizona potential habitat characterization removed areas > 1 house/10 acres, and areas of contiguous row crop agriculture > 1 $mi.^2$ (Hatten et al. 2002). The lack of equivalent data sets for New Mexico necessitated the use of alternative indices to human presence as they would apply to the suitability of potential jaguar habitat. We evaluated two separate data sets to potentially represent the effects of human density on potential jaguar habitat in New Mexico. We obtained 2000 U.S. Census Bureau data population data by census block, and U.S Census Bureau TIGER road files. The human population density provided the more direct index to human presence within the study area (Figure 3), but was not ideal for accurately locating the spatial extent of uninhabited areas. For example, "blocks" from Silver City area extended into the designated Forest Service wilderness areas.

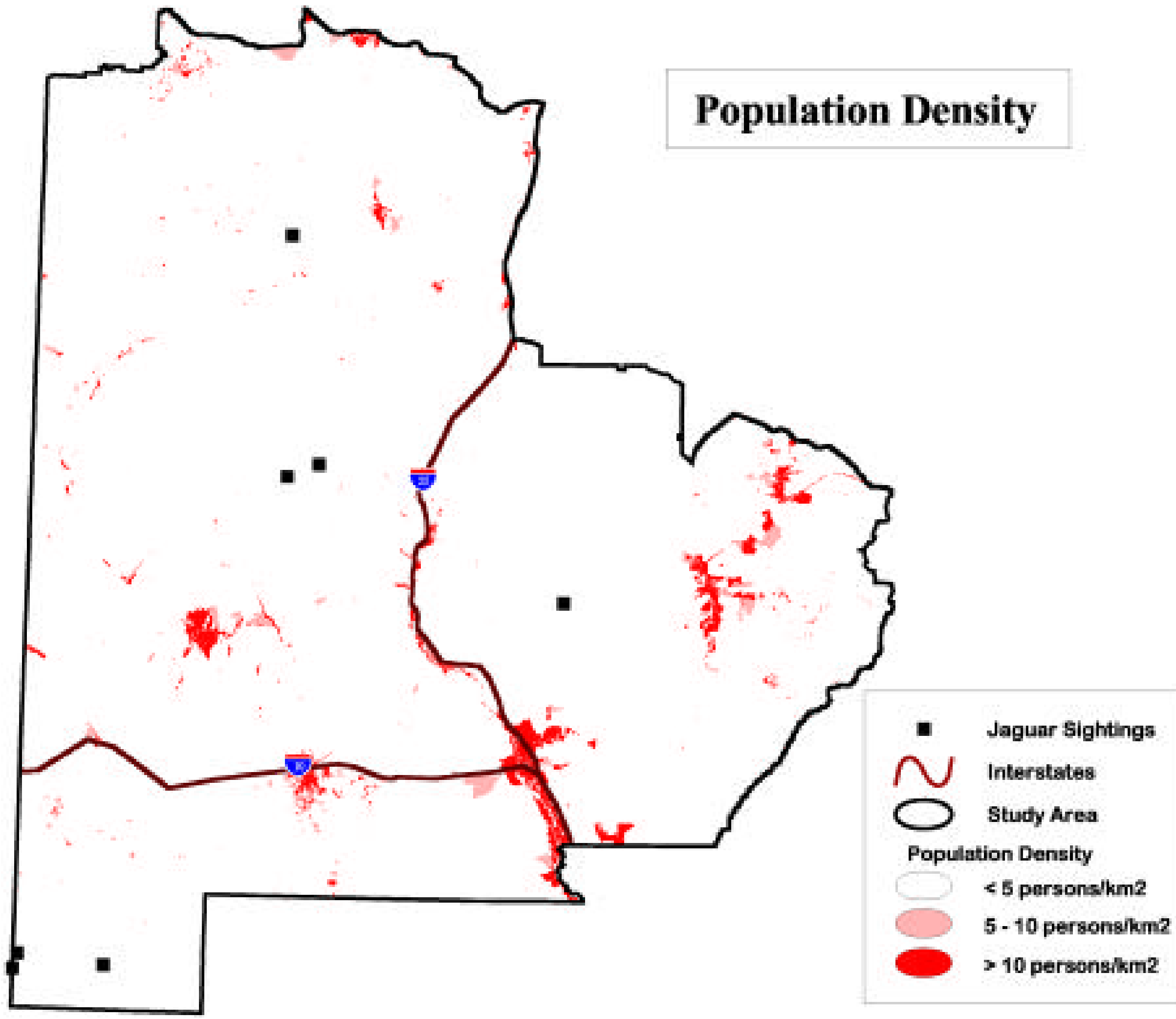

Figure 3. Population Density

In contrast to the human population density layer, the road density coverage offered a more indirect measure of human presence on the landscape. However, the presence of roads themselves can influence the suitability and use of potential habitats, and can offer a more spatially precise indicator of human presence on the landscape than census blocks. This data layer contained a small number of known errors, such as apparent roads within areas administratively closed to all motor vehicles. Roads within designated wilderness areas were erased to correct these known errors in the TIGER road data.

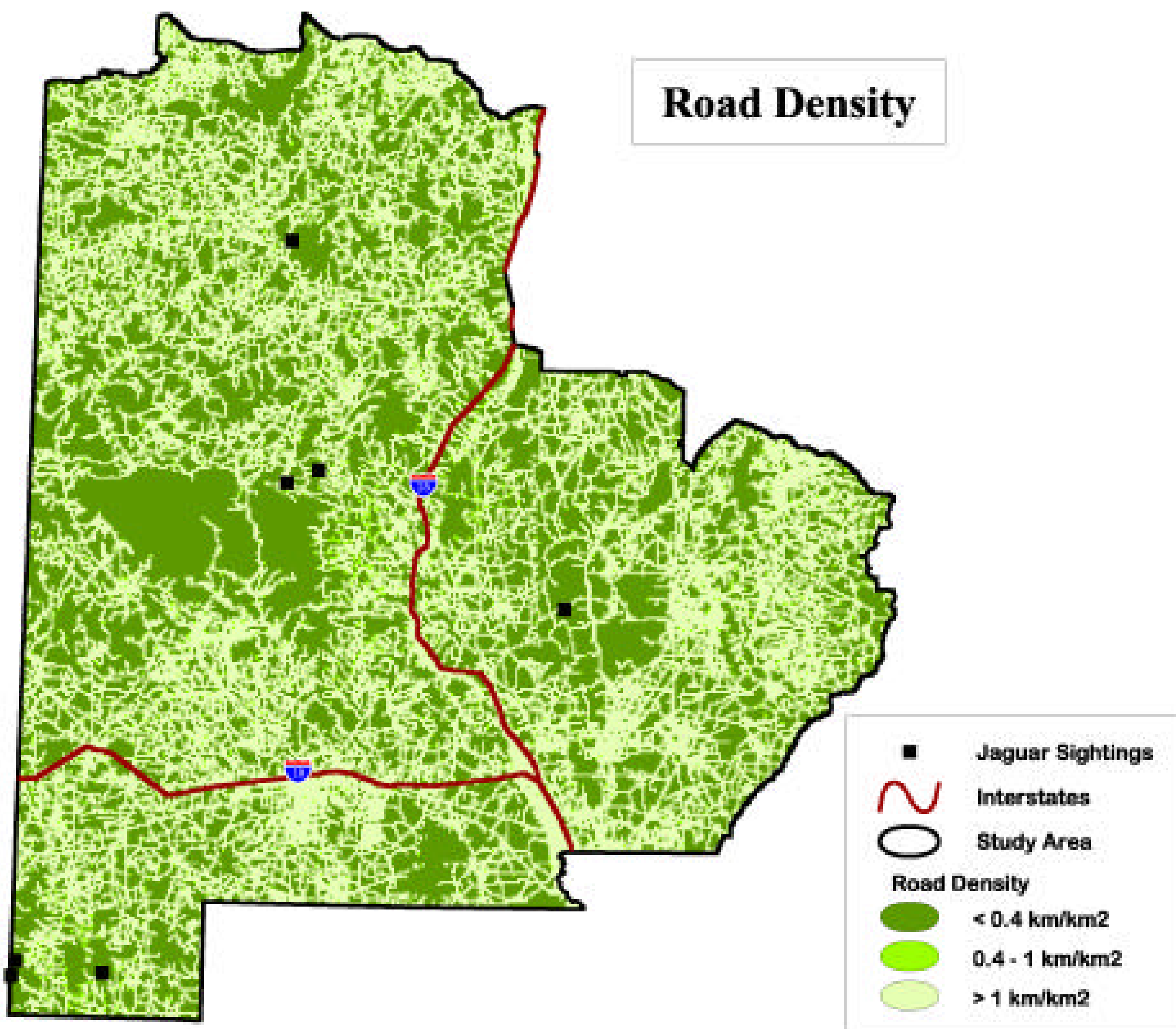

Figure 4. Road Density

We attempted to develop categories of road densities relative to jaguar habitat suitability, based on a review of available literature. However, the published literature regarding jaguar habitat use and roads is both limited and equivocal. In Central America, Rabinowitz and Nottingham (1986) documented regular use of timber roads (presumably unimproved) and trails by jaguars, and even suggested that these roads may serve as a limited resource used for hunting and directional travel. For carnivores in general, the impacts of high road density have been well documented and thoroughly reviewed (e.g., Noss et al. 1996, Carroll et al. 2001). Roads may have direct impacts to carnivores and carnivore habitats, including roadkill, disturbance, habitat fragmentation, changes in prey numbers or distribution, and providing increased access for legal or illegal harvest. In some cases, the relationship between use by large predators and road density has been quantitatively analyzed (Thiel 1985, Jensen et al. 1986, Van Dyke et al. 1986a, Fuller 1989, Mladenhoff et al. 1999). For example, a model of recolonizing wolves in northern Wisconsin used a road density of 0.45 km/km^2 to classify favorable vs. unfavorable habitat (Mladenhoff et al. 1999). Other studies have suggested that a suggested similar thresholds of road densities for mountain lions (Van Dyke et al. 1986b) and for brown bears in Europe (Clevenger et al. 1997). Based on examples from the published literature, we created a data layer of road density per square kilometer and classified it into the following categories: < 0.4, 0.4-1.0, and > 1.0 km roads/km^2. The lowest category was considered to be most suitable, and the highest category least suitable for potential jaguar habitat.

Vegetation Community

We evaluated biotic communities based on classifications described within Brown et al. (1980). The JAGSAG had considered several biotic communities to be potentially suitable for jaguars. The Arizona Upland Sonoran Desertscrub biome was a notable exclusion from the JAGSAG’s assessment of potential habitat, despite the occurrence of a few jaguar observations within that biome. However, the Arizona Upland Sonoran Desertscrub biome did not occur within New Mexico, and no biotic communities were eliminated from further analysis of potentially suitable habitats.

We did not attempt to conduct analyses of jaguar habitat use vs. availability based on observations from New Mexico, Arizona, or anywhere else within the United States. However, we considered the Madrean Evergreen Woodland biotic community (Figure 3) most similar to habitats used by breeding populations of jaguars in closest proximity to the southwestern United States. This biome encompasses over half of the documented kills of jaguars within the United States and Chihuahua (Brown and Lopez Gonzalez 2001). We therefore assigned a positive suitability value to the Madrean Evergreen Woodland biotic community. We did not consider any other biotic communities within New Mexico to be limiting to potential jaguar habitat in New Mexico, and did not assign negative suitability values to any other biomes found within the study area.

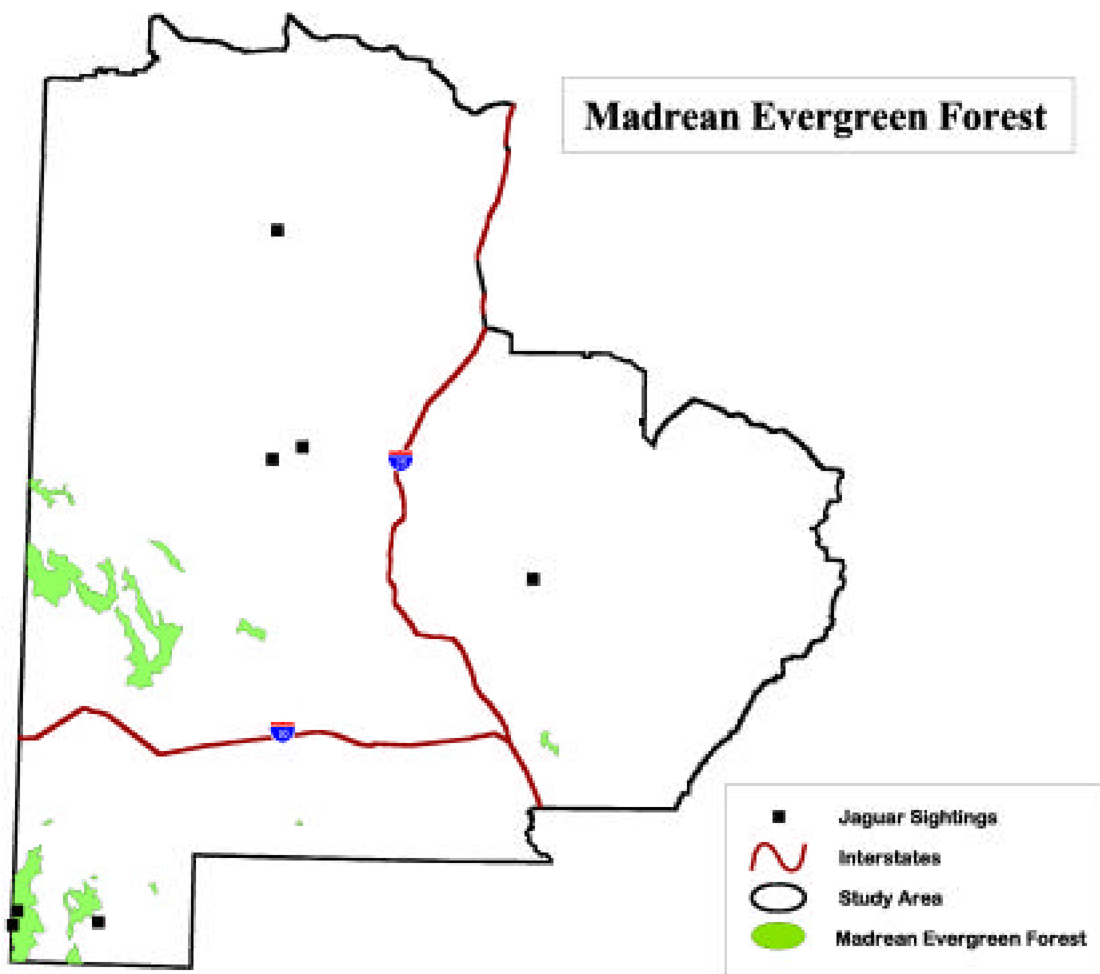

Figure 5. Madrean Evergreen Woodland Vegetation Community

Distance to Water

We created a model to generate a proximity to water index for the study area. The input data consisted of perennial and intermittent streams from the USGS National Hydrographic Dataset and the USGS GNIS data set. We did not attempt to incorporate anthropogenic point water sources (e.g., stock tanks), because it is unknown to what extent riparian vegetation (which is commonly absent from these anthropogenic water sources) influences the probability of their use by jaguars.

The proximity to water index classified the study area into categories based on proximity to both perennial and intermittent water sources (Figure 6). We used both the Arizona modeling suitability threshold of 10 km for proximity to streams or rivers (Hatten et al. 2002), plus an expanded category of lands within 16 km of a water source and a smaller distance of 5 km. We also weighted perennial sources over intermittent sources, and proximity to multiple water sources over proximity to a single source. A proximity to water index was developed by combining these buffered data sets in an arithmetic overlay.

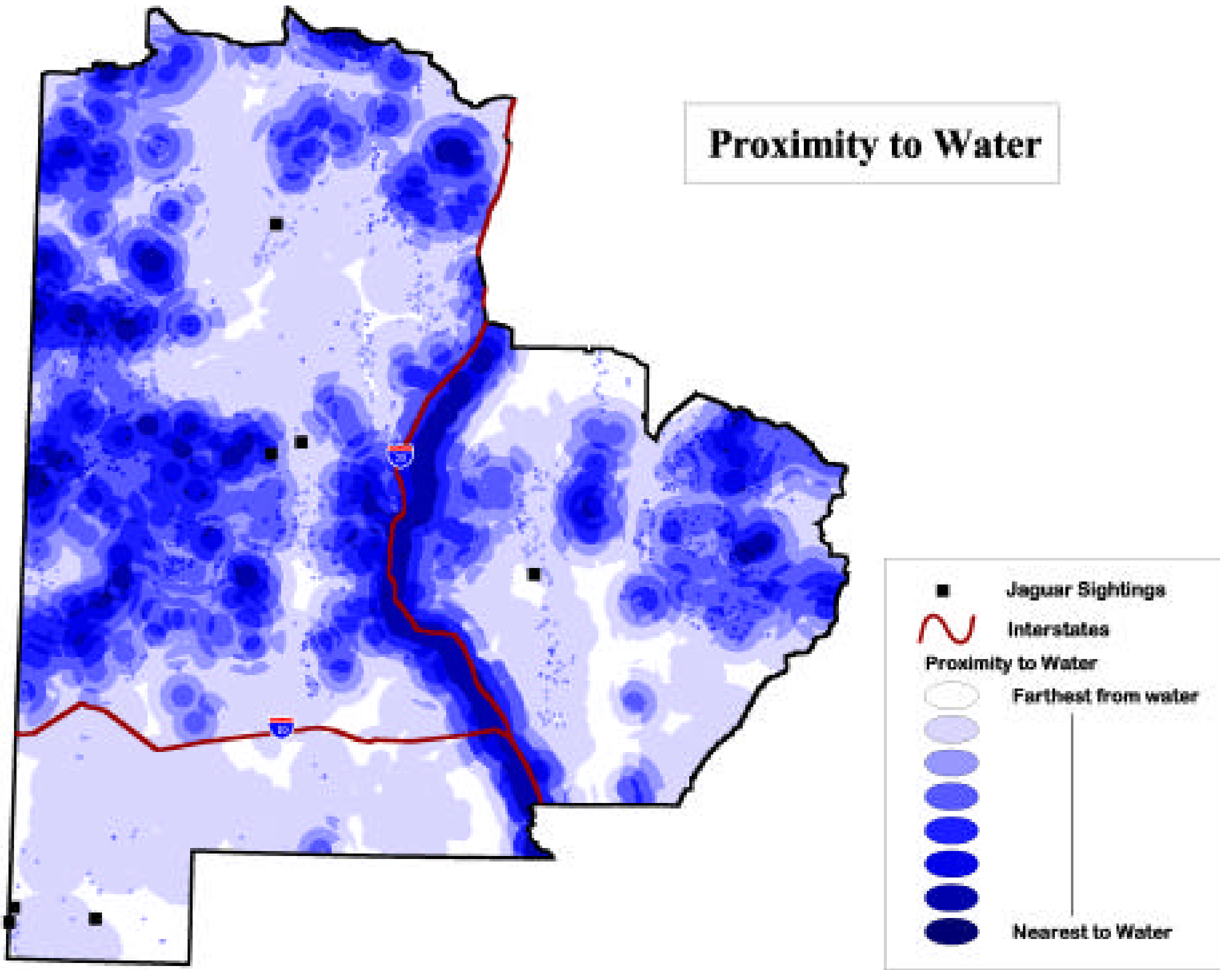

Figure 6. Proximity to Water Sources

Prey Availability

Jaguars have been documented to feed upon over 85 different prey species (Seymour 1989). Given the variety and adaptability in the jaguar's diet across its range, and the potential for changes in biomass of available large prey with changes in wildlife management, we did not attempt to evaluate total biomass of potential jaguar prey as a limiting factor.

The jaguar’s preferred prey has been described as terrestrial mammals > 1 kg (Seymour 1989, Lopez Gonzalez and Miller 2002). Applying this information to the southwestern United States, we expect jaguar prey to include, and jaguars to be sympatric with, the collared peccary (*Tayassu tajacu*), white-tailed deer (*Odocoileus virgianus*), mule deer (*O. hemionus*), elk (*Cervus elaphus*), and coatimundi (*Nasua nasua*). Despite the variation in jaguar diets, several authors have postulated that collared peccaries and deer are the staple foods of jaguars at the far northern end of their range (Findley 1975, Federal Register 1997, Rabinowitz 1997,
Brown and Lopez Gonzalez 2001).

We created a GIS layer (Figure 7) representing the combined distribution (indicating diversity of prey species present) of the five potential prey species listed above, using New Mexico Gap Analysis and Rocky Mountain Elk Foundation data layers. We doubled the weighting of the distribution for collared peccaries and white-tailed deer to reflect their assumed importance in the diet of jaguars within those areas of most recent jaguar sightings in New Mexico. In the overall model, we assigned a value proportional to the weighted number of prey species present in a grid cell.

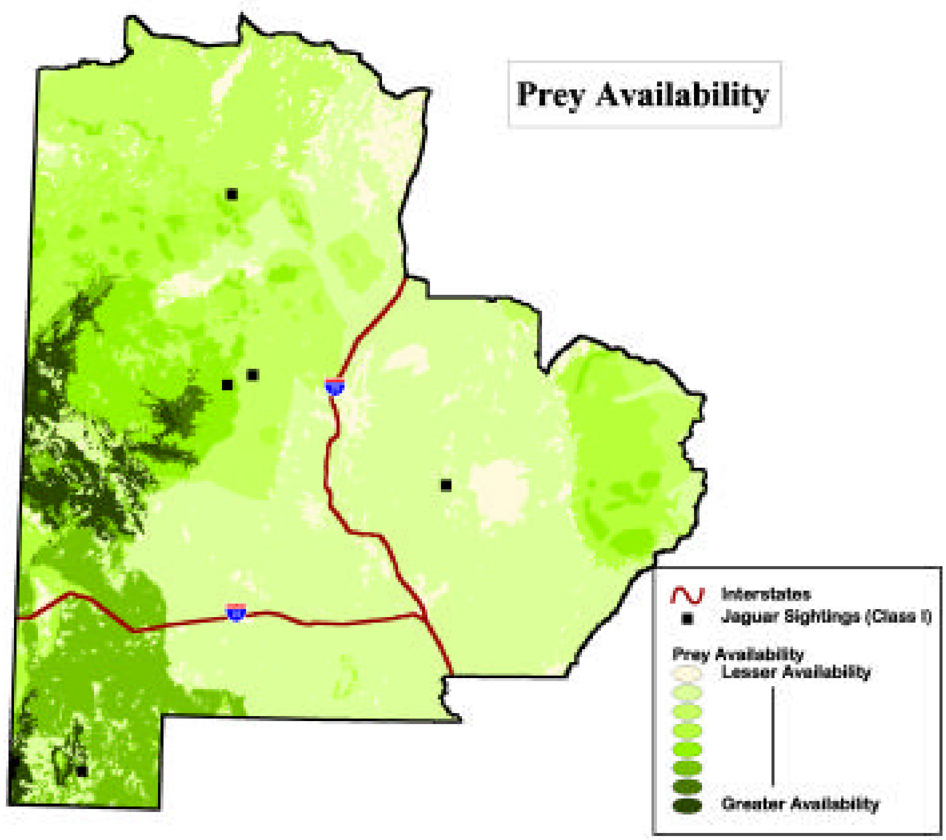

Figure 7. Distribution of Potential Jaguar Prey

Terrain Ruggedness

Rugged terrain has been modeled as being preferred by jaguars, based on its ability to provide cover for travel, escape, hunting, or other life-history needs (Hatten et al. 2002). We assessed terrain ruggedness with a moving window analysis of a digital elevation model. We compared the elevation of each 30-m cell to the 8 surrounding cells. The sum difference in elevation became the terrain ruggedness value for each cell (Riley et al. 1999)(Figure 6). The grid was classified into seven ruggedness categories based on natural breaks in the data. Incrementally higher weights were assigned to categories as the ruggedness values increased. The highest category of ruggedness (e.g., sheer cliffs) was considered to be too rough and was weighted less.

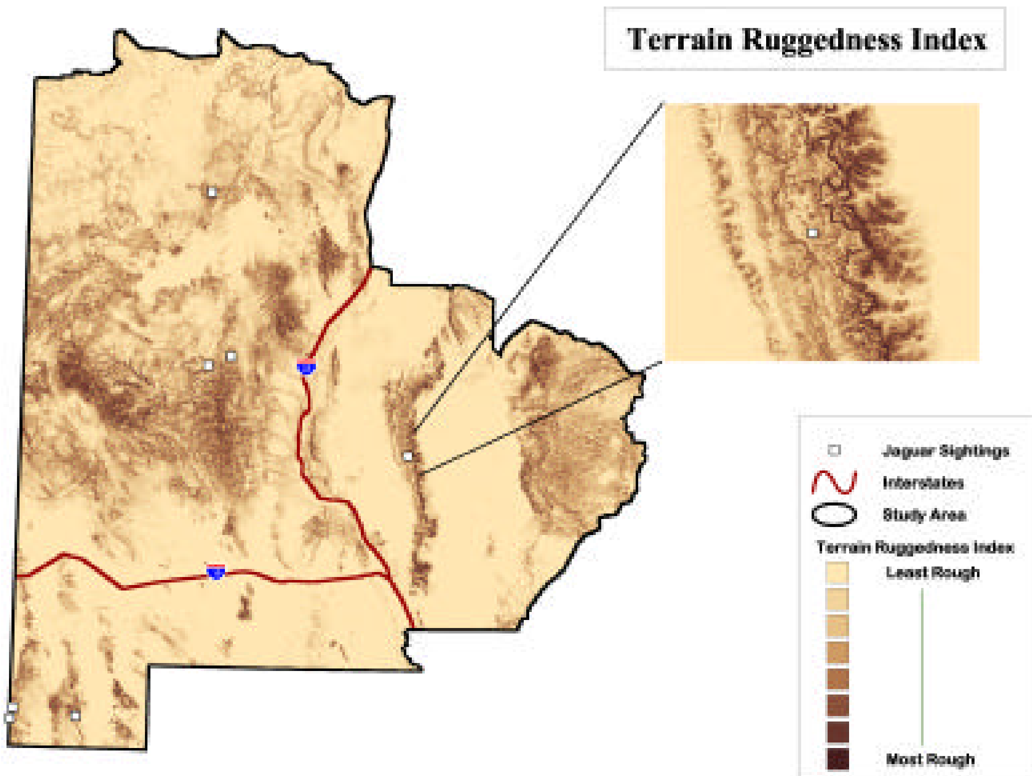

Figure 8. Terrain Ruggedness

RESULTS

We combined five potential habitat variables (road density, Madrean Evergreen Woodland biotic community, proximity to water, prey availability, terrain ruggedness) into a relative habitat suitability model. We classified the results of the combined potential habitat grid into five suitability categories based on natural breaks in the data (Figure 9). Two general locations within the study area contained relatively contiguous blocks of land that fell within the two highest relative suitability classes. The two areas were the Animas/Peloncillo Mountains of extreme southwestern New Mexico, and the portions of the Gila/San Francisco River drainages on the far west-central portion of the study area. The more rugged and remote portions of the Sacramento Mountains were also identified as having high potential habitat suitability, but were surrounded in all directions by areas of lower habitat potential. The two areas with the highest relative suitability are generally contiguous with the New Mexico-Arizona border, and the Animas/Peloncillo area also abuts the United States-Mexico border. The developed areas around the cities of Deming, Silver City, Las Cruces, and Alamogordo were rated as least suitable by the model. The three documented Class 1 or Class 2 sightings from the 1990s were from areas falling within the three highest relative suitability categories. All documented Class 1 or Class 2 sighting locations occurred in areas assigned a high ruggedness value, and terrain ruggedness was the single variable that appeared to have a high degree of correlation with locations of jaguar observations. This is likely due at least in part to the temporally static nature of this variable. Conversely, proximity to water appeared to have the least correlation with observed jaguar locations, and the 1990s locations were from the two categories of least proximity to water sources.

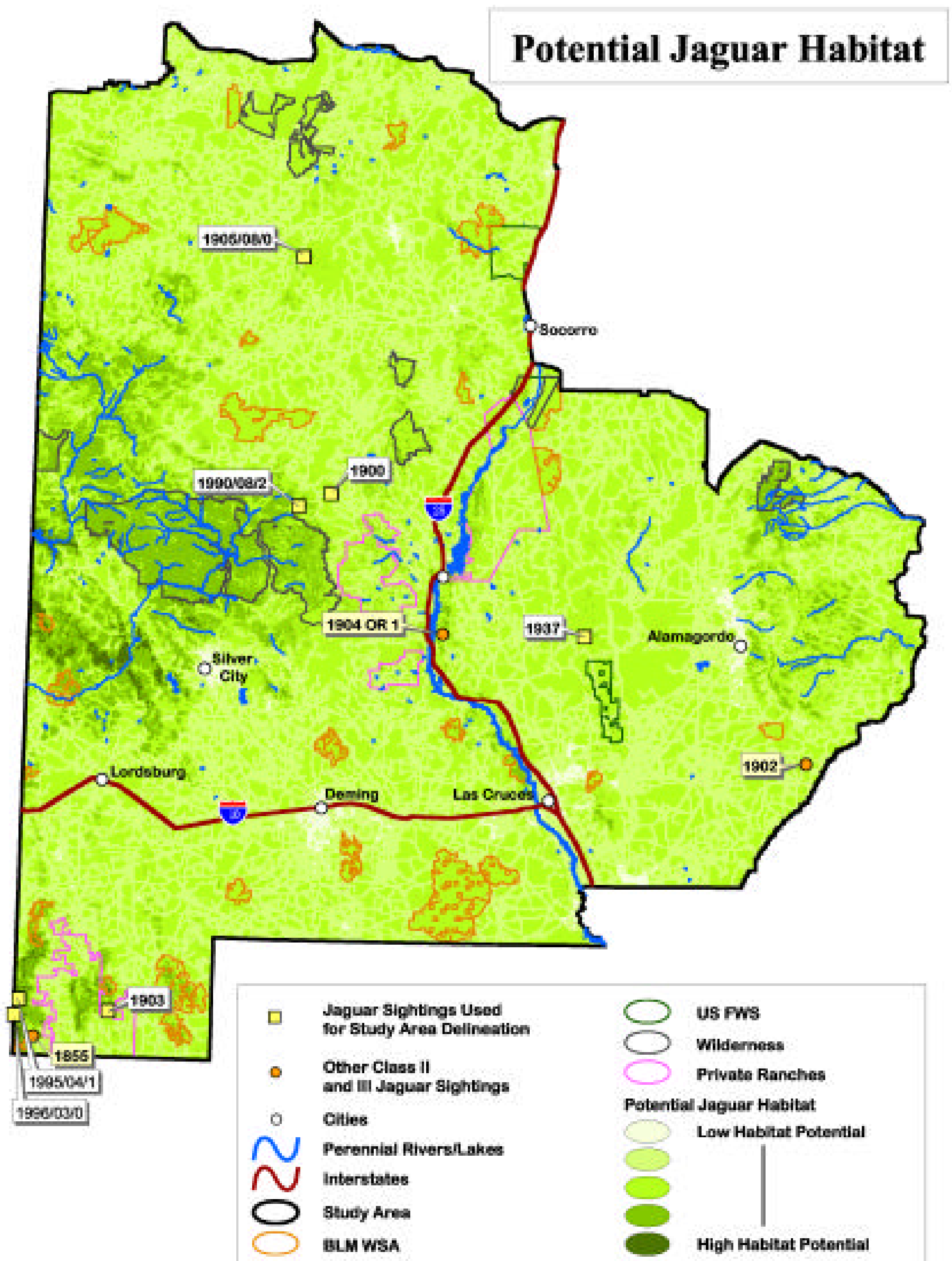

Figure 9. Results of Potential Jaguar Habitat Mapping in New Mexico

DISCUSSION

This study considered only current potential habitat for jaguars within the state of New Mexico. Historic range of jaguars in New Mexico is defined, in part, by reports of jaguars having been killed in New Mexico as far north as Colfax County, and as far east as Otero County (Findley 1975, Schmitt 1998). This is a much broader area than was evaluated as potential habitat within this study. However, no observations accompanied by physical evidence or reported as first-hand observations from a reliable source were documented in New Mexico for a period of over 50 years prior to the 1990s. During the 1990s, observers documented jaguar sightings, including photographic evidence of jaguars and jaguar tracks, in southwestern New Mexico (Glenn 1996, Brown and Lopez Gonzalez 2001). Although there are sufficient historical observations of jaguars (of varying degrees of reliability) from other portions of New Mexico, the limited number of observations from the past century suggests that landscape-level changes have reduced current potential habitat to fragmented patches that closer to extant populations of jaguars in northern Mexico.

The potential habitat suitability map appeared to be qualitatively consistent with jaguar observations in New Mexico over the last 50 years. Despite some differences in specific methodology used compared to jaguar habitat suitability mapping in Arizona (Hatten et al. 2002), the most highly suitable habitats from New Mexico generally connected with delineated areas of suitable habitat directly across the New Mexico-Arizona border. This finding provides some level of validation for the techniques and results of each study.

The relative suitability map for potential jaguar habitat in New Mexico identifies areas that would be most likely to support any jaguars that were present within those areas. It does not predict the probability of jaguars occurring within any specific area, nor does it predict the likelihood of any area to support a self-sustaining population of jaguars. The model does predict those areas expected to be most suitable for use by jaguars, and can lead to some evaluation of potential corridors and routes of travel for jaguars in the United States. For example, Barber (1902) predicted that jaguars were reaching the Mogollon Mountains of New Mexico by ascending the Gila River from the west, based on observations made from 1897-1902. The present degree of connectivity between potential jaguar habitats in New Mexico and those in both Arizona and Mexico can now be quantitatively and objectively evaluated, using results of this study and other jaguar habitat models for

Arizona and northern Mexico. A complete evaluation of the prospects for long-term persistence of the jaguar in the United States must encompass information regarding not only the availability of potential habitat, but must also consider the potential linkages to habitats that currently sustain breeding populations of jaguars.

Both theoretical and empirical studies of wildlife metapopulations indicate the vulnerability of small and peripheral populations or subpopulations, and their dependence on dispersal and recolonization from core populations (Grinnell 1922, Pulliam 1988, Stacey and Taper 1992, Fahrig and Merriam 1994). Management actions with positive impacts to jaguars will be necessary for the long-term persistence of jaguars in areas that do not currently support self-sustaining populations. In order to most effectively focus these actions on areas providing the greatest benefit to the jaguar, we recommend that habitat linkage modeling and least-cost movement analyses be performed (e.g., Walker and Craighead 1997, Singleton et al. 2002) for potential jaguar habitats in New Mexico, Arizona, and northern Mexico. Additional jaguar habitat use data from the northern end of the jaguar’s range is needed to test and improve the existing habitat models. Identification and implementation of appropriate habitat management actions for jaguar conservation will require fully engaged local land managers to refine existing habitat models, direct conservation actions to areas of greatest potential benefit, and to monitor the success of these actions.

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